Canadian Centre for Occupational Health and Safety

Centre canadien d'hygiène et de sécurité au travail

WORKPLACE NOISE AND NOISE MEASUREMENT

A Basic Guide

P88-23E

89-02860/

WORKPLACE NOISE AND NOISE MEASUREMENT

A Basic Guide

Prepared for

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December 1988

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WORKPLACE NOISE AND NOISE MEASUREMENT--A BASIC GUIDE

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This publication is available in both official languages.

Cette publication est disponible dans les deux langues officielles.

CCOHS NUMBER P88-23E
ISBN 0-660-12947-7
DSS CATALOGUE NUMBER CC273-2/88-23E

Published 1988

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PREFACE

This publication, in the form of questions and answers, explains the nature of workplace noise and basic measurement techniques. It is useful to people taking simple noise measurements, or reviewing the results of noise surveys. It does not discuss the effects of workplace noise on people or the methods of control.

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1. INTRODUCTION

Noise is one of the most common occupational health hazards. It is present in heavy industrial and manufacturing environments, as well as in farms, cafeterias, dishrooms, small shops, offices and schools.

The technology is available to reduce noise levels in most work environments. Reduction often involves engineering modifications to the source of the noise or to the workplace. Where technology cannot adequately control the problem, personal hearing protection, such as ear muffs or plugs, can reduce noise exposure.

As a first step in dealing with noise, workplaces need to identify areas or operations where excessive exposure to noise occurs. This publication explains the terminology used to describe noise exposure and the methods used to measure noise. It also presents information on the nature of noise.

2. WHAT IS NOISE?

What Are Sound and Noise?

Sound is what we hear. Noise is unwanted sound. The difference between sound and noise depends upon the listener and the circumstances. Rock music can be sound to one person and noise to another.

When an object vibrates, it causes slight changes in air pressure. These air pressure changes travel as waves through the air and produce sound. To illustrate, imagine striking a drum surface with a stick. The drum surface vibrates back and forth. As it moves forward, it pushes the air in contact with the surface. This creates a positive (higher) pressure by compressing the air. When the surface moves in the opposite direction, it creates a negative (lower) pressure by decompressing the air. Thus, as the drum surface vibrates, it creates alternating regions of higher and lower air pressure. These pressure variations travel through the air as sound waves (Figure 1).

The ear's hearing mechanism senses the sound waves and converts them into information which it relays to the brain. The brain interprets the information as sound. The hearing mechanism in the ear is sensitive enough to detect even small pressure waves. It is also very delicate--which is why loud sound may damage hearing.

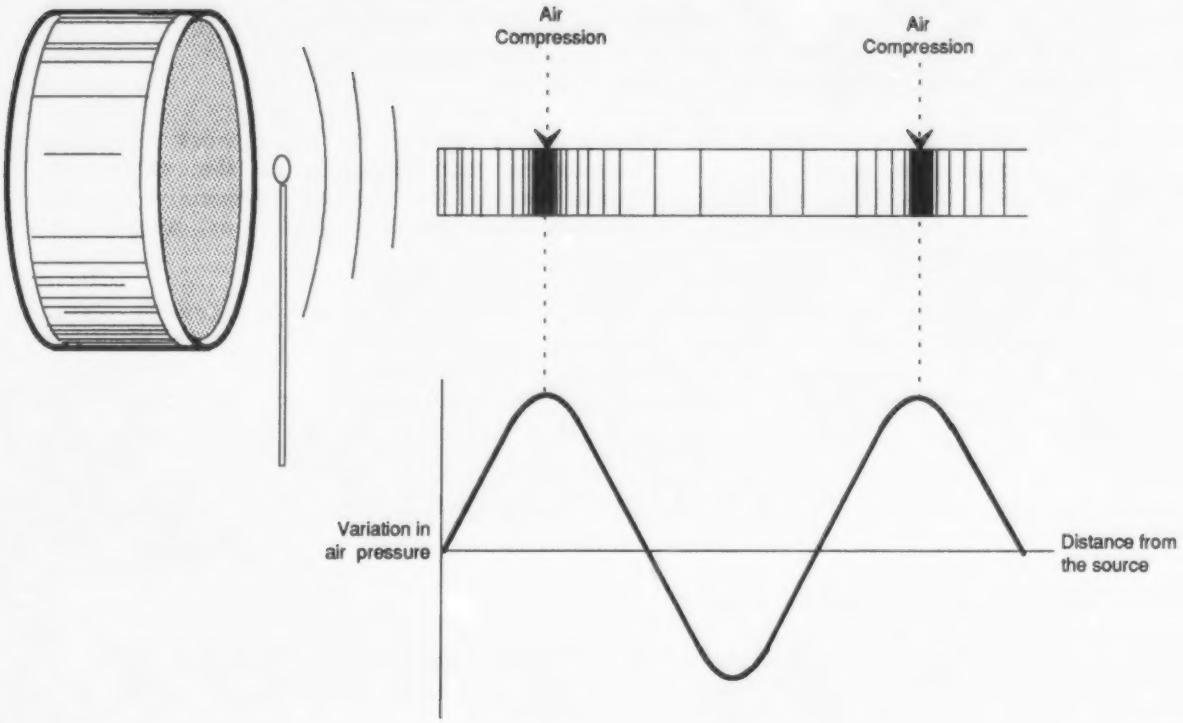

Figure 1 - Generation of sound waves

The properties of noise which are important in the workplace are:

- frequency
- sound pressure
- sound power
- time distribution

What Are Pitch and Frequency?

Frequency is the rate at which the source produces complete cycles of high and low pressure regions. In other words, frequency is the number of times per second that a vibrating body completes one cycle of motion. The unit used for frequency is the hertz (Hz = 1 cycle per second). We hear frequency as pitch. Low pitched or bass sounds have low frequencies. High-pitched or treble sounds have high frequencies. A healthy, young person can hear sounds with frequencies from roughly 20 to 20,000 Hz. The sound of human speech is mainly in the range 300 to 3,000 Hz.

What Is Sound Pressure?

Sound pressure is the amount of air pressure change a noise source creates. We hear sound pressure as loudness. If the drum in our example is hit very lightly, the surface moves only a very short distance and produces a faint sound. If the drum is hit harder, its surface moves farther from its rest position. As a result, the pressure increase is greater. To the listener, the sound is louder.

Sound pressure also depends on the environment in which the source is located and the listener's distance from the source. The sound produced by the drum is louder two metres from the drum if it is in a small bathroom, than if it is struck in the middle of a football field. Generally, the farther one moves from the drum, the quieter it sounds.

Sound pressure is usually expressed in units called pascals (Pa). A healthy, young person can hear sound pressures as low as 0.00002 Pa. A normal conversation produces 0.02 Pa. A gasoline-powered lawn mower produces about 1 Pa. The sound is painfully loud at levels around 200 Pa.

It is difficult to work with such a broad range of sound pressures. The decibel or dB scale is more convenient because it compresses the scale of numbers into a manageable range. The decibel is named after Alexander Graham Bell, the Canadian pioneer of the telephone who took great personal interest in the problems of deaf people.

Sound pressures converted to the decibel scale are called sound pressure levels (Lp). Appendix A gives a detailed explanation of decibels and sound pressure levels. Figure 2 compares sound pressures in pascals and sound pressure levels in decibels (dB). Sound pressure levels in decibels are always used when measuring the sound pressure or loudness of noise.

What Is Sound Power?

As the surface of the drum vibrates, it transfers energy to the air. The sound power is the sound energy transferred per second from the drum to the air. A noise source, such as a specific compressor or drum, has a given, constant sound power that does not change if the source is placed in a different environment.

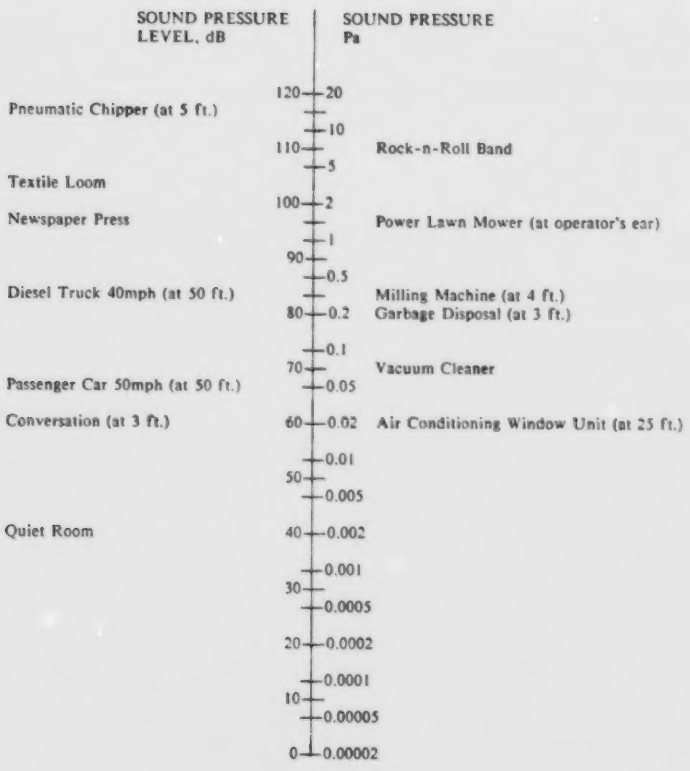

Figure 2 - A comparison of sound pressure level and sound pressure

Sound power is expressed in units called watts (W). An average whisper generates a sound power of 0.0000001 watts, a truck horn 0.1 W, and a turbo jet engine 100,000 W.

Like sound pressure, sound power (in W) is usually expressed as sound power levels (in dB) on the decibel scale. Appendix B provides examples of sound power level calculations.

Figure 3 relates sound power in watts to sound power level in decibels. Note that while the sound power goes from one trillionth of a watt to one hundred thousand watts, the equivalent sound power levels range from 0 to 170 dB.

What Is the Relation Between Sound Pressure and Sound Power?

Because the sound power of a noise source is constant and specific, it can be used to calculate the expected sound pressure. The calculation requires detailed information about the noise source's environment. Usually a noise source with a lower sound power generates less sound pressure.

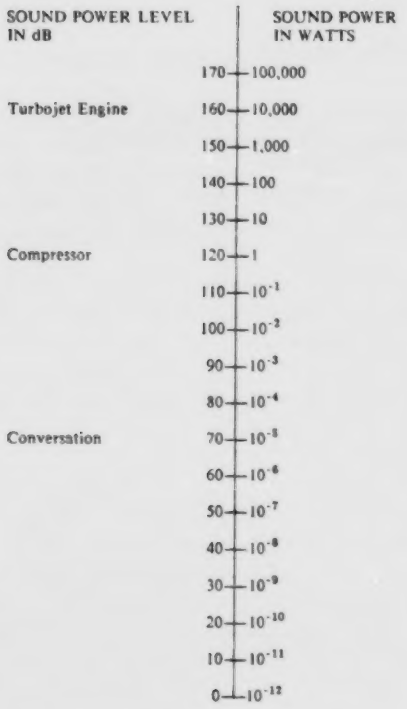

Figure 3 - A comparison of sound power level and sound power

The manufacturer can often provide the sound power of equipment. From the sound power of a compressor, one can calculate the expected sound pressure and sound pressure level at a certain location and distance.

This information can be helpful in determining possible noise exposures and how they compare to the noise guidelines.

How Does Time Distribution Affect Noise?

Noise can be continuous, variable, intermittent or impulsive depending on how it changes over time. The distinction between continuous, variable, and intermittent noise is not clearly defined. Continuous noise is noise which remains constant and stable over a given time period. The noise of boilers in a power house is relatively constant and can therefore be classified as continuous.

Most manufacturing noise is variable or intermittent. Different operations or different noise sources cause the sound changes over time. Noise is intermittent if there are periods of relative quiet mixed with the noise. As the time interval between periods of noise decreases, intermittent noise becomes impulse or impact noise.

Impulse or impact noise is a very loud noise which is produced in very short bursts (less than one second). Gun fire or the noise produced by punch presses are examples.

What Are A-weighted Decibels?

The sensitivity of the human ear to sound depends on the frequency or pitch of the sound. People hear some frequencies better than others. If a person hears two sounds of the same sound pressure but different frequencies, one sound may appear louder than the other. This is because people hear high frequency noise much better than low frequency noise.

Noise measurement readings can be adjusted to correspond to this peculiarity of human hearing. An A-weighting filter which is built into the instrument de-emphasizes low frequencies or pitches. Decibels measured using this filter are A-weighted and are called dB(A). Legislation on workplace noise normally gives exposure limits in dB(A). Table 1 lists examples of typical noise levels.

Table 1 - Typical noise levels

Noise source	dB(A)
pneumatic chipper at 1 meter	115
hand-held circular saw at 1 meter	115
textile loom	103
newspaper press	95
power lawn mower at 1 meter	92
diesel truck 50 km per hour at 20 meters	85
passenger car 60 km per hour at 20 meters	65
conversation at 1 meter	55
quiet room	40

How Are Noise Levels Added?

Sound pressure levels in decibels (dB) or A-weighted decibels [dB(A)] are based on a logarithmic scale (see Appendix A). They cannot be added or subtracted in the usual arithmetical way. If one machine emits a sound level of 90 dB, and a second identical machine is placed beside the first, the combined sound level is 93 dB, not 180 dB.

Table 2 shows a simple way to add noise levels.

Table 2 - Addition of decibels

Numerical difference between two noise levels [dB(A)]	Amount to be added to the higher of the two noise levels [dB or dB(A)]
0	3.0
0.1 - 0.9	2.5
1.0 - 2.4	2.0
2.4 - 4.0	1.5
4.1 - 6.0	1.0
6.1 - 10	0.5
10	0.0

Step 1: Determine the difference between the two levels and find the corresponding row in the left hand column.
Step 2: Find the number [dB or dB(A)] corresponding to this difference in the right hand column of the table.
Step 3: Add this number to the higher of the two decibel levels.

For instance, using the example of two machines each emitting a noise level of 90 dB:

Step 1: The numerical difference between the two levels is 0 dB (90-90 = 0), using the first row.
Step 2: The number corresponding to this difference of 0, taken from the right hand column, is 3.
Step 3: Add 3 to the highest level, in this case 90. Therefore, the resulting noise level is 93 dB.

3. WHAT ARE THE EXPOSURE GUIDELINES/STANDARDS FOR WORKPLACE NOISE?

Noise exposure guidelines and standards are typically given as the maximum duration of exposure permitted for various noise levels. They are often displayed in a table such as Table 3. There are two key factors which describe any such exposure duration table: the criterion level and the exchange rate.

What Is the Criterion Level?

The criterion level, often abbreviated as L_c, is the steady noise level permitted for a full eight-hour work shift. This is usually 90 dB(A), but in some jurisdictions it is 85 dB(A).

What Is the Exchange Rate?

As the sound level increases above L_c, the allowed exposure time decreases. This maximum exposure time is calculated by using an exchange rate, also called a "dose-trading relation" or "trading ratio." The exchange rate is the amount by which the permitted sound level may increase if the exposure time is halved.

There are two exchange rates currently in use: 3 dB(A) or the "3 dB rule," and 5 dB(A) or the "5 dB rule." These two exchange rates, with criterion levels of 85 dB(A) and 90 dB(A), give two different sets of exposure guidelines, as Table 3 shows.

Table 3a - Noise exposure guideline
criterion level = 90 dB(A)

3dB(A) Exchange Rate	Maximum Permitted Daily Duration (hours)	5dB(A) Exchange Rate
Allowable Level dB(A)		Allowable Level dB(A)
90	8	90
93	4	95
96	2	100
99	1	105
102	1/2	110
105	1/4	115

Table 3b - Noise exposure guideline
criterion level = 85 dB(A)

3dB(A) Exchange Rate	Maximum Permitted Daily Duration (hours)	5dB(A) Exchange Rate
Allowable Level dB(A)		Allowable Level dB(A)
85	8	85
88	4	90
91	2	95
94	1	100
97	1/2	105
100	1/4	110

The 3 dB(A) exchange rate is more stringent. For example, the maximum permitted duration for a 105 dB(A) noise exposure in the 3 dB(A) exchange rate is 15 minutes. With the 5 dB(A) exchange rate, it is one hour.

Most experts currently recognize the 3 dB rule as more logical. They argue that doubling the sound energy always results in a 3 dB(A) increase in the actual sound level. It would seem logical that if the sound level is doubled, then the allowable exposure time should be cut in half. It follows, then, that the allowable time should be halved for every 3 dB(A) increase in sound level. This is precisely the case if the 3 dB(A) exchange rate is used.

Table 4 shows the criterion levels and exchange rates used by different Canadian jurisdictions.

Table 4 - Canadian exposure standards/guidelines compiled August 1988

Jurisdiction	8-hour criterion Level, dB(A)	Exchange rate dB(A)	Impulse/impact[1]
Alberta	85	5	X
British Columbia	90	3	X
Manitoba	90	3	
New Brunswick	90	5	X
Newfoundland[2]	85	5	X
Nova Scotia[2]	85	5	X
Northwest Territories	90	5	X
Ontario[3]	90	5	
Prince Edward Island[4]	--	-	
Quebec	90	5	X
Saskatchewan	85	(3)[5]	
Yukon	85	3	X
ACGIH[6]	85	5	X

NOTES

1. In some jurisdictions, noted by "X," there is specific reference made to the maximum number of impulses per day for given peak sound levels.
2. Legislation quotes the most recent ACGIH guidelines.
3. New noise regulations (Designated Substances Regulation) are anticipated.
4. No specific numerical noise exposure standards are quoted in legislation.
5. Exchange rate of 3 dB(A) is not quoted in legislation. It is used as a guideline.
6. ACGIH (American Conference of Governmental Industrial Hygienists) is an organization which has no legal authority. It provides recommended exposure guidelines for chemical and physical agents in the workplace. These guidelines are used in the United States and in many other countries.

The regulations or guidelines in several jurisdictions treat impulse noise separately from continuous noise. A common approach is to limit the number of impulses at a given peak pressure over a workday. The exact figures vary slightly, but generally the regulations permit 10,000 impulses at a peak pressure of 120 dB; 1,000 impulses at 130 dB; and 100 impulses at 140 dB. These values are based on military studies, using gunshots as the impulse noise source. They rate the effects of the impulse noise alone, with little or no continuous background noise.

Alternatively, using a 3 dB(A) exchange rate, impulse noise can be considered jointly with any continuous noise, using the permissible exposure durations.

Besides permissible exposures, many Canadian noise regulations also include requirements for engineering controls and hearing protection.

4. HOW IS WORKPLACE NOISE MEASURED?

For occupational hygiene purposes, the sound pressure level is measured to determine noise exposures. Various instruments and techniques may be used. The choice depends on the workplace noise and the information needed.

What Types of Instruments Are Used for Measuring Noise?

The most common instruments used for measuring noise are the sound level meter, dosimeter and integrating sound level meter. Table 5 provides some instrument selection guidelines.

What Is a Sound Level Meter (SLM)?

The SLM consists of a microphone, some electronic circuits and a readout display. The microphone detects the small air pressure variations associated with sound and changes them into electrical signals. These signals are then processed by the electronic circuitry of the instrument. The readout displays the sound level in decibels. The SLM takes the sound pressure level at one instant in a particular location.

To take measurements, the SLM is held at arm's length at the ear height for those exposed to the noise. With most SLMs it does not matter exactly how the microphone is pointed at the noise source. The instrument's instruction manual explains how to hold the microphone. The SLM must be calibrated before and after each use. The manual also gives the calibration procedure.

With most SLMs, the readings can be taken on either SLOW or FAST response. The response rate is the time period over which the instrument averages the sound level before displaying it on the readout. Workplace noise level measurements should be taken on SLOW response.

Table 5 - Guidelines for instrument selection

Type of Measurement	Appropriate Instruments (in order of preference)	Result	Comments
Personal noise exposure	1) Dosimeter	Dose or equivalent sound level	Most accurate for personal noise exposures.
	2) ISLM*	Equivalent sound level	If subject is mobile, it may be difficult to determine a personal exposure, unless work can be easily divided into defined activities.
	3) SLM**	dB(A)	If noise levels vary considerably, it is difficult to determine average exposure. Only useful when work can be easily divided into defined activities and noise levels are relatively stable all the time.
Noise levels generated by a particular source	1) SLM	dB(A)	Measurement should be taken 1 to 3 metres from source (not directly at the source).
	2) ISLM	Equivalent sound level dB(A)	Particularly useful if noise is highly erratic; it can measure equivalent sound level over a short period of time (1 minute).
Noise survey	1) SLM	dB(A)	To produce noise map of an area; take measurements on a grid pattern.
	2) ISLM	Equivalent sound level dB(A)	For highly erratic noise.
Impulse noise	1) Impulse SLM	Peak pressure dB(A)	To measure the peak of each impulse.

* ISLM stands for Integrating Sound Level Meter
** SLM stands for Sound Level Meter

A Type 2 SLM is sufficiently accurate for industrial field evaluations. The more accurate and much more expensive Type 1 SLMs are primarily used in engineering, laboratory and research work. Any SLM that is less accurate than a Type 2 should not be used for workplace noise measurement.

An A-weighting filter is generally built into all SLMs and can be switched ON or OFF. Some Type 2 SLMs provide measurements only in dB(A), meaning that the A-weighting filter is ON permanently.

A standard SLM takes only instantaneous noise measurements. This is sufficient in workplaces with continuous noise levels. But in workplaces with impulse, intermittent or variable noise levels, the SLM makes it difficult to determine a person's average exposure to noise over a work shift. One solution in such workplaces is a noise dosimeter.

What Is a Noise Dosimeter?

A noise dosimeter is a small, light device that clips to a person's belt with a small microphone that fastens to the person's collar, close to an ear. The dosimeter stores the noise level information and carries out an averaging process. It is useful in industry where noise usually varies in duration and intensity, and where the person changes locations.

Wearing the dosimeter over a complete work shift gives the average noise exposure or noise dose for that person. This is usually expressed as a percentage of the maximum permitted exposure. If a person has received a noise dose of 100% over a work shift, this means that the average noise exposure is at the maximum permitted. For example, with a criterion level of 90 dB(A) and an exchange rate of 3 dB(A), an eight-hour exposure to 90 dB(A) gives a 100% dose. A four-hour exposure to 93 dB(A) is also a 100% dose, whereas an eight-hour exposure to 93 dB(A) is a noise dose of 200%.

Usually the manufacturer electronically adjusts dosimeters to the criterion level and exchange rate in use. You may have to adjust them to suit the exposure guidelines/standards in force in your jurisdiction.

Many dosimeters give an equivalent sound or noise level. This is the average exposure level for noise. It has the same total sound energy as the actual, variable sound levels to which a person is exposed over the same time period. Scientific evidence suggests that hearing loss is affected by the total noise energy exposure. If a person is exposed over an eight-hour work shift to varying noise levels, it is possible to calculate an equivalent sound level which would equal the same total sound energy exposure. This would have the same effect on the person's hearing as the variable exposure actually received (Figure 4).

What Is an Integrating Sound Level Meter (ISLM)?

The integrating sound level meter (ISLM) is similar to the dosimeter. It determines equivalent sound levels over a measurement period. The major difference is that an ISLM does not provide personal exposures because it is hand-held like the SLM, and not worn.

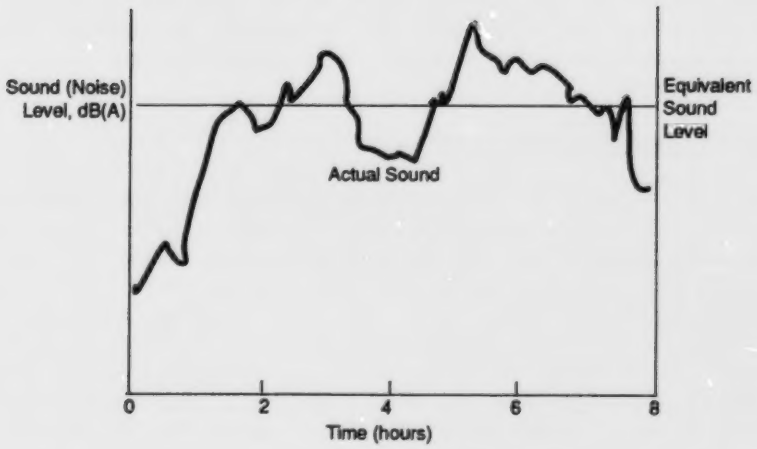

Figure 4 - Equivalent sound level for a sound whose loudness varies with time

The ISLM determines equivalent sound levels at a particular location. It yields a single reading of a given noise, even if the actual sound level of the noise changes continually. It uses a pre-programmed exchange rate, with a time constant that is equivalent to the SLOW setting on the SLM.

What Techniques Are Used for Measuring Noise?

Before taking any field measurements, it is important to determine the type of information required. Do the workplace noise levels vary throughout the day? Are the workers fairly mobile?

In a bottle washing and filling facility, for example, the noise levels vary over the work shift. Instantaneous noise measurements, taken with an SLM (Type 2, SLOW RESPONSE, A-filter), at one person's work station, ranged from 63 dB(A) to 114 dB(A) over the day, although levels most commonly ranged from 90 to 96 dB(A) and 104 to 107 dB(A). This information strongly suggested that there was a potential for excessive noise exposure. Because it was difficult to determine the extent of the problem, the worker was asked to wear a noise dosimeter over a full eight-hour work shift. At the end of the shift, the noise dosimeter indicated a 270% dose. This was a substantial exposure. In addition, the dosimeter provided an equivalent noise level of 97 dB(A). In other words, a constant eight-hour exposure to a steady, continuous noise of 97 dB(A) would have resulted in the same exposure. It would have had the same effect on hearing as the actual varying noise exposure that the worker received. Exposure guidelines (based on a 3 dB exchange rate) would permit less than two hours of this exposure. Some form of noise exposure reduction by means of noise control or hearing protection was clearly necessary.

An ISLM could also have been used in this example, particularly if the worker spent most of the work shift in a defined location, or the first half of the shift in one area and the remainder in another area. The ISLM could have provided equivalent sound level measurements and a fairly accurate exposure assessment.

How Is Impulse/Impact Noise Measured?

Measurements of impulse or impact noise depend on the guidelines and standards in force. Normally measurements of either peak noise levels together with the actual number of peaks, or percentage dose or equivalent sound levels are required. Where there is little background noise, as for example on an outdoor rifle range, the measuring of peak pressures may be most appropriate. In industrial settings, there is usually considerable background noise in addition to the impulse noise. In such cases, provided that a 3 dB(A) exchange rate is used, dosimeters or ISLMs which are sufficiently sensitive to respond well to peaks may be more appropriate. One can account for all of the noise, continuous and impulse, in the one measurement.

What Is a Frequency Analysis?

Noise measurements are usually taken to assess exposure risks. This is done by obtaining either a single dB(A) level or a noise dose/equivalent sound level. Sometimes it is necessary to determine the actual frequency distribution of the noise. A frequency analysis is a more detailed measure of the noise level at each pitch or frequency. But in practice, narrow frequency bands are used.

The audible range of frequencies (approximately 20 to 20,000 Hz) has been divided into 11 frequency bands for this purpose. These are called octave bands. An octave band filter set can be attached to an SLM to measure the sound level in each octave band.

The frequency analysis is usually needed only for the selection of appropriate engineering control methods.

What Is a Noise Survey?

A noise survey takes noise measurements throughout an entire plant or section to identify noisy areas. This is usually done with an SLM. A reasonably accurate sketch showing the locations of workers and noisy machines is drawn. Noise level measurements are taken at a suitable number of positions around the area and are marked on the sketch. The more measurements taken, the more accurate the survey. A noise map can be produced by drawing lines on the sketch between points of equal sound level.

Noise maps, like Figure 5, provide very useful information by clearly identifying areas of potential noise hazard.

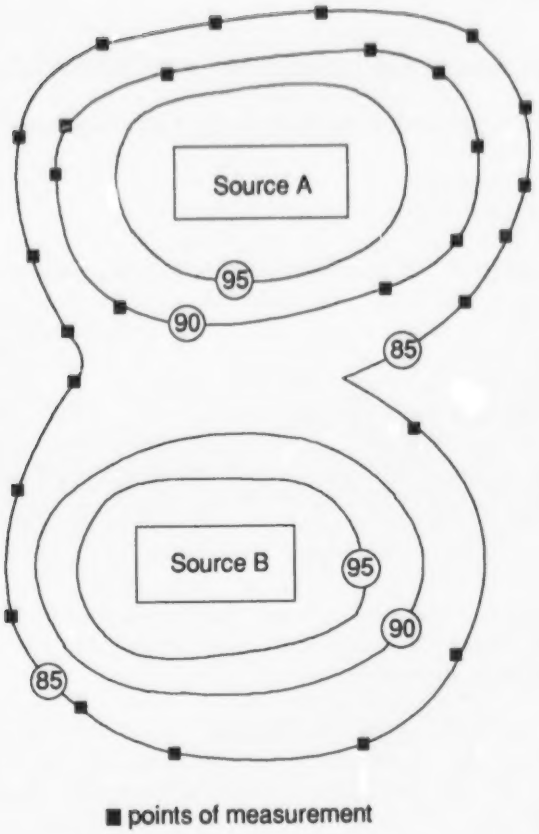

Figure 5 - An example of a noise survey map

APPENDIX A

Sound Pressure Level Calculations

Sound pressure level in decibels is defined in the following way:

$$dB = 20 \log \frac{\text{Sound Pressure}}{\text{Reference Pressure}}$$

The "log" or logarithm of a number is a mathematical manipulation of the number, based on multiples of 10. It is the exponent that indicates the power to which the number 10 is raised to produce a given number. For example, the logarithm of 10 is 1 since 10 is multiplied by itself only once to get 10. Similarly, the logarithm of 100 is 2 since 10 times 10 is 100. The logarithm of 1000 is 3 since 10 times 10 times 10 is 1000. Therefore

log(1)	= 0	Since $10^0 = 1$
log(10)	= 1	Since $10^1 = 10$
log(100)	= 2	Since $10^2 = 100$
log(1000)	= 3	Since $10^3 = 1000$

The logarithm scale simply compresses the large span of numbers into a manageable range. In other words, the scale from 10 to 1000 is compressed, by using the logarithms, to a scale of 1 to 3.

The decibel scale for sound pressures uses as the reference pressure the lowest noise that the healthy young person can hear (0.00002 Pa). It divides all other sound pressures by this amount when calculating the decibel value. Sound pressures converted to the decibel scale are called sound pressure levels. These are abbreviated L_p. So, the sound pressure level of the quietest noise the healthy young person can hear is calculated in this way:

$$L_p = 20 \log \frac{0.00002}{0.00002} = 20 \log (1) = 20 \times 0 = 0 \text{ dB}$$

The sound pressure level or L_p in a very quiet room, where the sound pressure is 0.002 Pa, is calculated

$$L_p = 20 \log \frac{0.002}{0.00002} = 20 \log (100) = 20 \times 2 = 40 \text{ dB}$$

The sound pressure level of a typical gasoline-powered lawn mower, which has a sound pressure of 1 Pa, is calculated

$$L_p = 20 \log \frac{1}{0.00002} = 20 \log (50\,000) = 20 \times 4.7 = 94 \text{ dB}$$

APPENDIX B

Sound Power Level Calculations

Sound power levels or L_W are determined by the following formula:

$$L_W = 10 \log \frac{\text{Sound Power}}{\text{Reference Power}}$$

The reference power is one trillionth of a watt (0.000000000001 W).
Therefore

$$L_W = 10 \log \frac{\text{Sound Power}}{0.000000000001}$$

Thus, the sound power level associated with an average whisper, which has a sound power of 0.0000001 W, is calculated

$$L_W = 10 \log \frac{0.0000001}{0.000000000001} = 50 \text{ dB}$$

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